Guidance on Soil Performance Standards

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Wisconsin Department of Natural Resources
P.O. Box 7921, Madison, WI 53707

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PURPOSE

This document discusses the use of soil performance standards and the application of soil performance standards to closure of contaminated soil sites. Soil performance standards offer an alternative to numerical soil standards for determining a soil cleanup standard for contaminated properties. Soil performance standards can only be used to address soil contamination - they can not be used in place of meeting numeric groundwater standards listed in ch. NR 140, Wis. Adm. Code. If there is groundwater contamination at the site or facility, remedial action to prevent or contain new releases of contaminants to the groundwater and to restore groundwater quality within a reasonable period of time must be implemented.

This guidance is not intended to be used as the sole reference for soil performance standards. Rather, it is intended to be used along with published references, guidance from others more experienced with soil performance standards, information from training courses and current journals. The material presented is based on available technical data and information and the knowledge and experience of the authors and the peer reviewers.

DISCLAIMER

This document is intended solely as guidance, and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. This guidance does not establish or affect legal rights or obligations, and is not finally determinative of any of the issues addressed. This guidance does not create any rights enforceable by any party in litigation with the State of Wisconsin or the Department of Natural Resources. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

This guidance is based on requirements found in chs. NR 140, 720, 722, 724, and 726, Wis. Adm. Code; the Hazardous Substance Spill Law, s. 292.11, Wis. Stats., the Environmental Repair Statute, s. 292.31, Wis. Stats., and the Groundwater Law, s. 160.23 and 160.25, Wis. Stats.

OTHER RELEVANT GUIDANCES

This guidance may be more complete when used in conjunction with:

Guidance for Cover Systems for Soil Performance Standard Remedies Publication RR-709.

Application of Soil Performance Standard Guidance, Publication RR-676
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR676.pdf

Case Close Out and the Requirements for Institutional Controls and VPLE Insurance, Publication RR-606
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR606.pdf

Checklist of Documents for GIS Registry Packet, Publication RR-688,
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR688.pdf

Guidance On Natural Attenuation For Petroleum Releases, Publication RR-614
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR614.pdf

Understanding Chlorinated Hydrocarbon Behavior in Groundwater: Investigation Assessment and Limitations of Monitored Natural Attenuation, Publication RR-699
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR699.pdf

Determining Residual Contaminant Levels Using The EPA Soil Screening Level Web Site, Publication RR-682
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR682.pdf

Interim Guidance on Soil Cleanup Levels for Polycyclic Aromatic Hydrocarbons (PAHs), Publication RR-519-97
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR519.pdf

Interim Guidance on Use of Leaching Tests for Unsaturated Contaminated Soils to Determine Groundwater Contamination Potential, Publication RR-523-97
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR523.pdf

This list will be expanded as additional guidances are developed.

These guidances may be obtained by:

A. Sending a request to: Public Information Requests, Bureau for Remediation and Redevelopment, Department of Natural Resources, P.O. Box 7921, Madison, WI 53707.
B. Calling the publication request line at (608)-264-6009.
C. Downloading the files from the internet at www.dnr.state.wi.us/org/aw/rr/errhw/.

Questions regarding this guidance should be directed to Theresa Evanson – RR/3, WDNR, P.O. Box 7921, Madison, WI 53707, phone number 608-266-0941, email Theresa.Evanson@dnr.state.wi.us.

This guidance will be updated as needed. Comments and concerns may be sent to "Guidance Revisions", Gary Edelstein, P.E. - RR/3, WDNR, P.O. Box 7921, Madison, WI 53707, phone number 608-267-7563, email Gary.Edelstein@dnr.state.wi.us.

1.0 INTRODUCTION

Section NR 720.19(2), Wis. Adm. Code, allows soil performance standards to be used in place of generic residual contaminant levels for soil listed in Tables 1 & 2 in ch. NR 720 or site-specific residual contaminants levels (RCLs) for soil (refer to publication RR-682). Any remedial action that mitigates a contaminant exposure pathway can include a soil performance standard. The term “performance standard” refers to the manner in which remedial actions (or, in some cases, existing site conditions) prevent exposure to contaminants, or will result in a decrease in contaminant concentrations, or both. The effectiveness of the remedial action will determine whether or not the "soil performance standard" is achieved. The remedial action must be implemented and maintained at a site or facility with soil contamination, such that any contamination that exceeds generic or site-specific residual contaminant levels (if calculated)[1] is contained and/or remediated. To be effective as a soil performance standard, the selected remedial action must be maintained permanently or until applicable numeric standards are achieved or until the remedial action is replaced by another remedy. In all cases the soil performance standard must be designed, implemented and maintained in order to protect public health, safety, welfare and the environment. Soil performance standards can be applied only in cases where the soils are treated or managed in-situ at a site or facility. Contaminated soil that has been excavated must be managed as a solid or hazardous waste. Chapter NR 718, Wis. Adm. Code, applies to excavated contaminated soil that is not a hazardous waste.

Soil performance standards may be developed during remedy selection under NR 722 and may provide the basis for case closure. Examples of performance standards include placing a barrier cap over contaminated soil which will limit infiltration and will be maintained and repaired for as long as necessary to protect human health and the environment, or demonstrating that natural attenuation of groundwater contains and remediates the contaminants leached from soils (i.e. demonstrating that the contaminant plume is stable or shrinking due to natural attenuation). In these examples, reduced infiltration or the natural attenuation processes are “performing” to contain and remediate the environmental contaminants. Once a performance standard has been established, no further action with regard to the contaminated soil is necessary as long as the conditions that are required by or affect the performance standard are maintained.

There are several ways to establish whether a selected remedy is performing to protect human health and the environment. At minimum, establishing a soil performance standard requires evaluation during the remedy selection phase and verification during the implementation phase.

1. Remedy Selection Phase. NR 722 sets out the process for identifying, evaluating, and selecting remedial actions. NR 722.09(2)(a) requires that soils be restored in compliance with NR 720. Any number of considerations may affect the choice of remedial options including volume of contaminated soil, type of contamination, area available for soil treatment, alternative disposal options, future land use, etc. A Remedial Action Options Report (RAOR) should

[1] It may not be necessary to determine the generic or site-specific numeric RCLs for contaminants as long as all contaminant pathways for all those contaminants in an area are addressed by the remedial action, provided the remedial action remains in place, is maintained as appropriate and remains effective. For example, if a cover is placed that extends to the known boundary of the clean area, and that cover addresses all pathways for the contaminated soil, then it isn't necessary to determine the numeric RCLs for as long as the cover adequately addresses the pathway and remains protective. It may be necessary to determine RCLs in the future if the remedy is changed or replaced.

document the process used to select a soil performance standard. If a RAOR is not prepared for the site, then the closure report should document the process used to determine that the soil performance standard is protective of human health and the environment.

2. Implementation Phase. In all cases, field verification is required to demonstrate that the selected remedy performs to the standard established for the site or facility. For example, after installing a barrier cap to protect against contaminant infiltration to groundwater, monitoring must be used to establish that groundwater quality is protected at the present time and to support projections that the barrier will protect groundwater quality in the future.

2.0 SELECTION OF A REMEDIAL ACTION WITH A SOIL PERFORMANCE STANDARD

Selection of a soil performance standard requires a knowledge of administrative code requirements as well as of the migration pathways being protected.

2.1 ADMINISTRATIVE CODE REQUIREMENTS

Before a remedial action that utilizes a soil performance standard may be selected, it must be demonstrated that:

1. The selected remedy has been evaluated in compliance with ch. NR 722. Standards for selecting remedial actions are specified in ch. NR 722, Wis. Adm. Code. To comply with ss. NR 722.07(4) and NR 722.09(2), soil performance standards for a proposed remedial action must ensure that there is no threat of adverse impact to groundwater, surface water, human health, safety or welfare or to sensitive environments, posed by the residual soil contamination.

2. The selected remedy is in compliance with NR 724. The selected remedial action will be operated and maintained in compliance with ch. NR 724, where applicable, until applicable standards are achieved.

3. The selected remedy will be implemented and maintained such that there is:

    a. No adverse impact on groundwater. If groundwater has not been affected at a site with soil contamination, the soil performance standard must ensure that there is no future groundwater impact (i.e., contaminant levels entering groundwater can be no greater than a preventive action level (PAL) unless an exemption is granted under s. NR 140.28, Wis. Adm. Code).

        If groundwater contamination exists at the site, no expansion of the groundwater plume is allowed. New releases of contaminants to the groundwater that exceed NR 140 standards must be prevented or contained and a groundwater remedial action must be implemented to restore groundwater quality within a reasonable period of time. Natural attenuation can not be relied upon as the exclusive remedy at sites or facilities with an expanding groundwater plume.

    b. No adverse impact on surface water or sensitive environments. Discharges to surface water, wetlands, and other sensitive environments may not result in standard exceedances, in accordance with s. NR 722.09(2)(c). A soil performance standard must minimize migration of contaminants and be in compliance with NR 102 to 106. If a

discharge is taking, or will take place, the discharge must be evaluated to determine the effectiveness of a proposed soil performance standard.

c. No adverse impact on human health, safety or welfare. No adverse impact on human health includes dermal contact, ingestion, inhalation, etc. of soil contaminants. Vapor migration through soils into enclosed spaces, such as basements, are also a risk to health or safety. Under some conditions, impermeable surface covers will exacerbate lateral vapor migration in the subsurface. Therefore installation of a soil performance standard has the potential to create new contaminant migration pathways. This must be evaluated before acceptance of a soil performance standard.

2.2 EXPOSURE OR MIGRATION PATHWAYS

When choosing a remedial action for soil cleanup, all exposure or migration pathways must be addressed. There are a number of pathways not addressed in this guidance (vapor migration, utility trenches, etc.). Each site is unique and the specific pathways of concern must be determined for each site.

The most common pathways for soil contamination that may be of concern at a specific site or facility are direct contact with soil contaminants through inhalation or ingestion and contaminant leaching to groundwater. These pathways are addressed below. It must be emphasized that all applicable exposure or migration pathways must be assessed at each site and the remedial approach must address each applicable pathway.

1. *Protection from Direct Contact with Soil Contaminants*. A soil performance standard to protect human health from direct contact would typically involve capping the contaminated soil with an appropriate barrier and ensuring that the barrier is maintained until the direct contact threat no longer exists (i.e., generic or site specific residual contaminant level soil standards are met). Impermeable barriers may consist of compacted clay, geomembranes, asphalt or concrete roadways and parking lots, building foundations, etc. If the contaminants are not likely to leach from the soil (e.g., PCBs), permeable barriers may be acceptable for limiting direct contact exposure. A direct contact performance standard will generally require long term maintenance to protect a barrier cap from cracking, erosion, freeze/thaw damage, animal damage, and other damage that may compromise the effectiveness of the barrier. Barrier caps will require a regular (at least annual) inspection and maintenance program, including the regular repair and/or replacement of any cracked or deteriorated areas. Responsible parties (RPs) and their consultants must include, as part of their evaluation of remedies that rely on such barriers, a discussion of how inspection and maintenance will be assured over time (otherwise, it can not be concluded that the barrier will continue to be effective). Permeable barrier design and maintenance is discussed in greater detail in “Guidance for Cover Systems for Soil Performance Standard Remedies”, RR-709.

When a soil cover, cap or engineered structure is used to prevent direct contact with soil contaminants within four feet of the ground surface, **a deed restriction is required** at the time of closure as well as **a soil GIS listing**. See Section 3.0 of this guidance for information on deed restrictions.

Direct contact with contaminated soils at depth is also possible if subsurface excavation of the contaminated soil occurs. Therefore, even if soils exceeding direct contact limits are not within four feet of the surface, a performance standard must be established to limit direct contact exposure to subsurface contamination. A deed restriction or deed notice may be required in

accordance with NR 726.05(8)(c) to ensure an adequate remedy is applied and to ensure that precautions are taken (e.g., use of personal protective equipment) if excavation does take place.

2. *Protection of Groundwater from Infiltration of Contaminants*. Where soil contaminants may leach to groundwater and groundwater contamination is less than NR 140 ES levels, the goal of a soil performance standard is to reduce soil contaminants leaching to groundwater to below NR 140 PALs. Where contaminants have already leached to the groundwater above NR 140 ES levels, the responsible party may demonstrate that a proposed remedy will contain any releases of contaminants to the groundwater that exceed NR 140 PALs as well as remediate the groundwater contaminant plume to meet enforcement standards within a reasonable period of time.

a. Soil contamination with groundwater contamination less than NR 140 ES levels. Performance standards do not allow additional contamination of the environment. If a leachable soil contaminant has not yet reached groundwater, the soil performance standard must ensure that the contaminant will not affect groundwater in the future (i.e., a PAL can not be exceeded in groundwater beneath the soil contamination unless an exemption is granted under s. NR 140.28). Empirical evidence (e.g., monitoring well data, lysimeters, etc.) will be necessary to demonstrate that the soil performance standard will protect groundwater from contamination. An example of a performance standard to protect groundwater from leaching of soil contaminants could include the allowable rate of leaching of soil contaminants into the groundwater (in concentrations no greater than a PAL) after an impermeable barrier has been installed.

b. Soil contamination with groundwater contamination above NR 140 ES levels. Where soil and groundwater contamination exist together, the proposed remedy should explicitly address cleanup actions for both media. An action taken to address contaminated groundwater may provide a basis for establishing a performance standard for leaching of soil contaminants to groundwater, if the remedy will contain and remediate groundwater contamination that exceeds NR 140 standards. Any groundwater remedy (passive or active) that meets NR 140 standards can qualify as a soil performance standard. There are a number of active groundwater remedies that can control and remediate groundwater contaminants. Therefore, it can be established that those remedies meet a soil performance standard for the groundwater pathway by containing and remediating contaminants leaching from soils.

   An impermeable barrier may be an effective remedy to reduce contaminant leaching through soil into groundwater and may help reduce contaminant concentrations in groundwater to below enforcement standards. Design and maintenance of impermeable barriers is discussed in greater detail in “Guidance for Cover Systems for Soil Performance Standard Remedies”, RR-709.

   Natural attenuation of groundwater contaminants can also serve as basis for establishing a soil performance standard. Demonstrating that natural attenuation contains and remediates groundwater contaminants may serve as a soil performance standard at a site or facility if:

   i. It can be documented that naturally occurring processes are containing and reducing the mass and concentration of groundwater contaminants and reducing the concentration of soil contaminants.

ii. Groundwater contaminant concentrations will be reduced below NR 140 ES levels within a reasonable period of time.
iii. Human health and the environment are protected.

The following administrative code sections are applicable to all three of the critieria listed above: ss. NR 140.24(2); NR 140.26(2)(a); NR 724.13(1); and NR 726.05(2)(b), Wis. Adm. Code.

Once it is established that natural attenuation mechanisms are effective in controlling and remediating a plume, these processes must continue to operate until ch. NR 140 groundwater standards are met. There are situations that can interfere with or change natural attenuation mechanisms (e.g., an upgradient contaminant source affecting the concentration of electron acceptors/nutrients entering the site/facility). Long-term monitoring and maintenance requirements should be structured to address these concerns, where applicable.

Deed restrictions are required (NR 726.05(8)(b)(3)) whenever a structure, such as a building or surface barrier is used to protect the groundwater pathway. Deed restrictions or deed notices may be required under other circumstances if they are needed to protect human health or the environment (NR 726.05(8)(c)). See Section 3.0 of this guidance for more information on deed restrictions and deed notices.

3.0 REQUIREMENTS FOR CASE CLOSURE USING SOIL PERFORMANCE STANDARDS

3.1 VERIFICATION AND MAINTENANCE OF SITES USING A SOIL PERFORMANCE STANDARD AND REQUESTING CASE CLOSEOUT

When closure is requested for a site for which a soil performance standard has been established, the effectiveness and adequacy of the remedial action and long-term maintenance of the remedy must be verified. Verification of the effectiveness and adequacy of the remedial action must be conducted by the responsible party prior to requesting closure. Capping actions to limit direct contact can be easily verified by establishing that a direct contact route of exposure no longer exists. It is more difficult to verify reduced leaching of soil contaminants to groundwater. If fate and transport modeling has been performed to evaluate contaminant leaching to groundwater, a method to verify the results of the modeling in the field should be proposed to the Department. If natural attenuation is proposed as the mechanism containing and remediating a groundwater plume, the natural attenuation processes must be verified in the field before this remedy can qualify as a soil performance standard and case closure requested. The applicable administrative codes include NR 726.05(2), NR 140.24 Table 5 (para. #12) and NR 140.26 Table 6 (para. #8).

When a case is closed after verifying the effectiveness and acceptability of the remedial action at the site or facility, all components of the remedy (e.g., a barrier cap, natural attenuation) must be maintained permanently or until the contamination is reduced to the point where applicable standards are met and the pathways of concern no longer present a risk to human health or the environment. Barrier caps will require regular (at least annual) inspections and a maintenance program, including the regular repair and/or replacement of any cracked or deteriorated areas, to ensure the long-term effectiveness of the soil performance standard.

The closure request must identify who will be responsible for long term care and maintenance and indicate how transfer of these responsibilities will occur as the property changes ownership. The Department, prior to granting final case closure, may require maintenance agreements and/or deed restrictions. If the soil performance standard is not maintained, the Department can reopen the closed site or facility under either of the following circumstances:

a. the conditions in the case closure decision have not been complied with, or

b. the Department can prove that "contamination on or from the site or facility poses a threat to public health, safety or welfare or the environment" under the authority of s. NR 726.09, Wis. Adm. Code.

3.2 INSTITUTIONAL CONTROLS - DEED RESTRICTIONS AND DEED NOTICES

1. *Deed Restrictions and Deed Notices*. Conditions where deed restrictions are required for case closure are set forth in section NR726.05(8)(b). Specific conditions requiring a deed restriction include:

a. Where a site is to be closed after soils have been remediated based on industrial RCLs.
b. Where a building prevents access and therefore prevents completion of a site investigation to determine the degree and extent of residual contamination.
c. Where some type of soil cover, cap or other engineered structure is used to contain soil RCLs based on protection of groundwater.
d. Where maintenance of a cover or cap is necessary to prevent direct exposure to residual soil contamination.

Where closure is conditioned on the recording of a deed instrument, the RP is required to record the deed instrument within 90 days after conditional closure is granted, and provide documentation to the Department that the deed instrument has been recorded within 120 days after conditional closure is granted. A deed restriction or deed notice may be required in limited situations other than those described above if there are site specific circumstances for which a deed notice or restriction would be necessary to adequately protect human health, safety or the environment. More information can be found in the Case Close Out and the Requirements for Institutional Controls and VPLE Insurance, Publication RR-606, http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR606.pdf.

2. *Removal of a deed restriction or deed notice*. Sites closed with a deed instrument (including groundwater use restrictions that were previously required) still have the option of later requesting unconditional closure from the Department. Responsible persons or other interested parties may request that the Department issue an affidavit that can be recorded at the county register of deeds office to give notice that the recorded deed instrument is no longer needed, if both of the following conditions are satisfied:

a. When soils contamination is shown to be below the generic or site-specific RCLs as determined by procedures found in NR 720.
b. When the levels of groundwater contamination fall below NR 140 ES levels, the RP or person requesting unconditional closure needs to provide information to shows that
    i. the contamination has fallen below the ch. NR 140 preventive action limits (PALs), or
    ii. the site qualifies for an NR 140.28 PAL exemption.

3.3 GIS REGISTRY OF CLOSED REMEDIATION SITES (GIS REGISTRY)

Wisconsin administrative code requires that a site is listed on an internet accessible database, called the GIS Registry of Closed Remediation Sites (GIS Registry) if either of the following conditions exist:

a. Soil contamination above generic (NR 720.09 or .11) or site specific RCLs (NR 720.19) exists on a source property or on any off source property within the contaminated site boundaries.
b. Groundwater contamination above NR 140 ES levels exists on a source property or on any off source property within the contaminated site boundaries.

When a performance standard is applied as a final remedy, a site does not need to meet applicable NR 720 generic or site-specific RCLs at the time of closure. However, the site must be listed on the GIS Registry until the applicable standards are met.

1. *GIS Registry and Contaminated Soils*. Rule revisions that went into effect on August 1, 2002, provide that sites with residual soil contamination exceeding applicable NR 720 generic or site-specific soil standards be placed on the GIS Registry. Each of the following conditions requires that closed sites be placed on the GIS Registry:

a. exceedances of applicable generic or site-specific RCLs anywhere on the site, regardless of the depth of soil contamination.
b. sites requiring a deed restriction under NR 726.05(8)(b) except those sites that close using industrial RCLs.
c. sites with residual soil contamination above applicable standards in the smear zone.

A site is placed on the GIS Registry after site closure is granted. Closure requests are submitted to the agency with administrative authority for the site and must be accompanied by the required data package and registry fees. The Department of Natural Resources maintains the GIS Registry and receives the data packages and Registry fee. Fees are specified in NR 749. The data required for listing a site on the GIS Registry with residual soil contamination is specified in NR 726.05(2)(a)3 and NR 720.05(3)(b). If groundwater contamination is also present at the time of closure, a combined groundwater – soil data package can be submitted for inclusion of the site on the GIS Registry.

The Department has a guidance to help consultants and owners submit the information needed for the GIS Registry. The guidance is called the Checklist of Documents for GIS Registry Packet, Publication RR-688, http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR688.pdf. The list of information required is also included in the Case Summary and Closeout form, #NR4400-202.

2. *GIS Registry and Contaminated Groundwater*. Contaminated sites with NR 140 ES exceedances in groundwater are listed on the GIS Registry when site closure is approved. The GIS Registry has replaced the requirement for a groundwater use restriction on properties with residual groundwater contamination exceeding an ES. NR 726 requires that the responsible party (RP) send a letter to all owners of properties with NR 140 ES exceedances. The letter (found in Appendix A, NR 726) offers the property owners the opportunity to provide technical information supporting any argument that they may want to make as to why closure may not be appropriate, as well as informing them that their property will be included on the GIS Registry.

Sites formerly closed with a groundwater use restriction have also been included on the GIS Registry. (However, sites closed with deed restrictions or soil standards exceedances prior to August 1, 2002, have not been added to the GIS Registry.)

Closure requests are submitted to the agency with administrative authority for the site and must be accompanied by the required data package. Fees are to be sent to the DNR and are specified in NR 749. The Department of Natural Resources maintains the GIS Registry and receives the data packages from the other agencies. The data required for listing a site on the GIS Registry with groundwater contamination is specified in NR 726.05(2)(a)2 and NR 720.05(3)(a).

See the internet link listed in paragraph 3.2.2.1 for a checklist of documents required for submittal of a GIS Registry data package.

3. *Removal of sites from the GIS Registry*. Sites can be removed from the GIS Registry if information demonstrating that the applicable standards have been met is provided to the Department with a complete request for revising the Registry. Options for removal from the GIS Registry include:

a. requesting a general liability clarification letter if splitting a property and removing the unaffected portion from the GIS Registry, or
b. submitting a new closure request for the entire site once standards are met, or
c. requesting technical assistance to have a property that is not the source property removed from the GIS Registry if applicable standards are met.

Fees will vary depending on the type of request. If approved, a letter or affidavit would be issued, that could be recorded with the deed, indicating the change in site conditions.

3.4 OTHER INSTITUTIONAL CONTROLS

Other forms of institutional controls (such as zoning changes) can be used to provide supplemental protection. However, zoning can be changed at any time and may not provide the long term protection inherent with land use restrictions recorded at the county Register of Deeds office for a specific property. Before closure, the Department will consider the permanence of any institutional control that is proposed or has been put in place and the protection it affords to the public and environment.

4.0 EXAMPLES OF SOIL PERFORMANCE STANDARDS

See the following references for examples of and requirements for applying soil performance standards:

Guidance for Cover Systems for Soil Performance Standard Remedies, Publication RR-709

Application of Soil Performance Standard Guidance, Publication RR-676
http://www.dnr.state.wi.us/org/aw/rr/archives/pubs/RR676.pdf

Guidance On Natural Attenuation For Petroleum Releases, Publication RR-614

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Understanding Chlorinated Hydrocarbon Behavior in Groundwater: Investigation Assessment and Limitations of Monitored Natural Attenuation, Publication RR-699
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